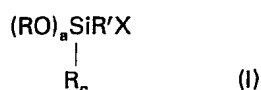


(21) Application No 8012664
 (22) Date of filing 17 Apr 1980
 (30) Priority data
 (31) 120197
 (32) 11 Feb 1980
 (33) United States of America (US)
 (43) Application published 3 Sep 1981
 (51) INT CL³
 C23C 13/02
 (52) Domestic classification
 C7F 1V1 2A 2F 2H 2L 2U
 2V 2Y 2Z1 2Z2 2Z3 3E 4H
 4M 4N 4W 4X
 (56) Documents cited
 None
 (58) Field of search
 C7B
 C7F
 (71) Applicant
 Dow Corning Corporation,
 Midland, Michigan
 48640, United States of
 America
 (72) Inventor
 James Bradshaw McGee
 (74) Agent
 Elkington and Fife,
 High Holborn House,
 52/54 High Holborn,
 London WC1V 6SH

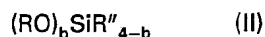
(54) **Improved Adhesion of Metal Coatings to Solid Substrates**

(57) A method of forming an adherent metal surface on a substrate comprises:

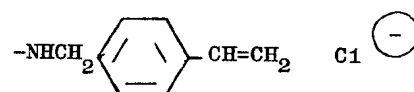
(i) treating a solid substrate with at least one organofunctionalsilane, or a partial hydrolysate(s) thereof, having the general formula (I):



or a mixture of such an organofunctional silane or the partial hydrolysate(s) thereof with a second silane, or a partial hydrolysate(s) thereof, which has the general formula (II):



in which formulae R is an alkyl radical of 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a —CH₂CH₂CH₂NHCH₂CH₂— radical, X is an —NH₂



—SH, OH or Cl radical, R'' is a phenyl radical, or an alkyl radical of 1—4 carbon atoms, and a and b each have a value of 2 or 3, c has a value of 0 or 1 and a+c=3;

(ii) drying the silane treated surface until the majority of volatile materials have been removed; and, thereafter,

(iii) depositing a metal on the silane treated surface to form a thin continuous film or coating thereon.

SPECIFICATION

Improved Adhesion of Metals to Solid Substrates

This invention relates to improved adhesion of metals to solid substrates.

There are many applications where it is desirable to form thin metallic films or coatings on various solid substrates. An example of such an application is the formation of silvered mirrors wherein very thin films or coatings of silver metal are deposited from chemical solution onto glass or similar substrates. Also, large reflectors for solar applications have been formed from vapor deposited silver or aluminum on solid substrates.

Some of the problems associated with prior art methods of forming thin metallic coatings on solid substrates have been the cumbersome application methods, for example, in producing silvered mirrors from chemical solution and, the inability to retain the metallic coating on the solid substrate for long periods of time. Also, in vapor deposition, vacuum metallizing, ion plating, spraying and similar methods, the metallized surface can only retain its aesthetic value if the substrate has been pre-treated with some composition which can mask or eliminate the scratches, pits and voids in the solid substrate. Such materials are generally curable organic coatings which are first coated onto the solid substrates at such thicknesses that they will physically fill the scratches, pits and voids, and are then cured. The metallizing is then carried out on the surface of the organic coating. Unfortunately, because of the presence of these organic "basecoats", the manufacturer is faced with a variety of adhesion problems between the basecoats and the solid substrate and the basecoat and the thin metallic film or coating. This problem is enhanced considerably when the manufactured item is intended to be used outdoors and is subject to the ravages of the weather.

What is needed therefore is an improved method of forming adherent metallic films or coatings on solid substrates and improved metallic coated materials.

According to the present invention there is disclosed an improved method of adhering a thin metallic film or coating to a solid substrate. The improved method utilizes a specific silane or mixtures of silanes to strongly adhere the thin metallic film or coating to solid substrates.

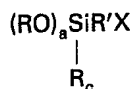
It has been known for a number of years that silanes are useful for bonding many materials to many various surfaces. It is generally recognized that silane coupling agents are not universal coupling agents such that any given silane will bond all materials to all substrates. Instead, it is generally accepted that specific silanes can be used for adhesion of specific materials to specific substrates, that is, the silane must be matched to the application and it cannot be assumed that all silanes will work in all applications.

In a recent British patent, Number 1,550,532, issued August 15, 1979, it is disclosed that thin films or coatings of metals can be adhered to plastic substrates by the use of a combination of alkoxysilanes, alkylsilicates and copolymers of alkyl acrylate or alkyl methacrylate with hydroxyalkyl acrylates or hydroxyalkyl methacrylates. This patent discloses that the inventive composition therein serves two purposes i.e. the polymeric material is a film former and the silane enhances adhesion of metal overcoat. The alkoxy silanes shown there are of the formula $R_nSi(OR')_{4-n}$ wherein n is 1, 2 or 3, R is a C_1-C_6 hydrocarbon group and R' is a C_1-C_4 alkyl group. This prior art material and method appears to work quite well so long as articles for use indoors are contemplated. It has been observed that this material does not have adequate adhesion of the deposited metal to the polymeric film which results in loss of adhesion of the thin metallic film.

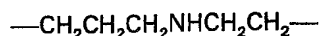
It has now been found that the adhesion of thin metal films to various substrates can be enhanced by the use of certain silanes and silane mixtures on certain substrates such that the articles prepared using the inventive method are durable, weatherable and have brilliance and enhanced specularly.

What is disclosed herein is a method of forming an adherent continuous thin metal surface on a substrate and the articles prepared thereby.

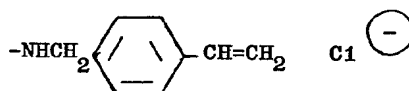
Thus, what is disclosed is a method of forming an adherent metal surface on a substrate by (i) treating a solid substrate with at least one organofunctional silane, or the partial hydrolysate thereof, having the general formula:



or a mixture of such an organofunctional silane or the partial hydrolysate thereof with a second silane, or the partial hydrolysate thereof, which has the general formula $(RO)_bSiR''_{4-b}$ in which formulae R is an alkyl radical of 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a

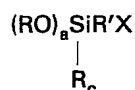


radical, X is an $-NH_2$,

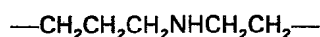


—SH, OH or Cl radical, R" is a phenyl radical, or an alkyl radical of 1—4 carbon atoms and *a* and *b* each have a value of 2 or 3, *c* has a value of 0 or 1 and *a*+*c*=3; (ii) drying the silane treated surface until the majority of volatile materials have been removed; and, thereafter, (iii) depositing a metal on the silane treated surface to form a thin continuous film or coating thereon.

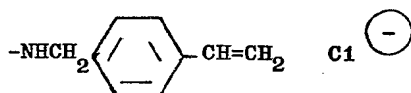
The organofunctionalsilanes used in step (i) have the general formula:



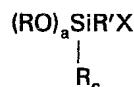
wherein R is an alkyl radical of 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a



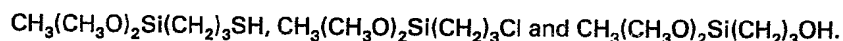
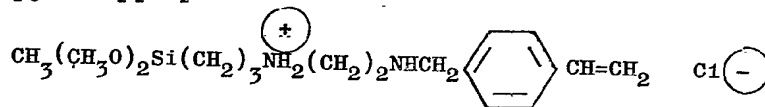
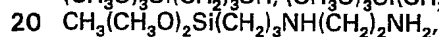
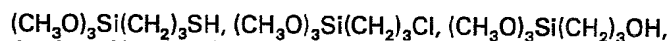
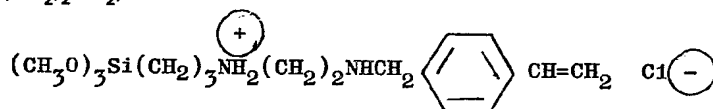
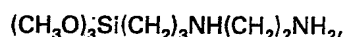
radical, X is an —NH₂,



—SH, OH or Cl radical, R being preferably the methyl radical, *a* has a value of 2 or 3; *c* has a value of 0 or 1 and *a*+*c*=3. Thus, contemplated within the scope of the formula:

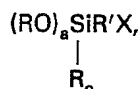


are such organofunctional silanes as



It should be noted that, contemplated within the scope of this invention, are the partial hydrolysates of these organofunctional silanes. By "partial hydrolysate", as used herein we mean the water soluble or water-miscible product formed when the organofunctional silane is treated with water to hydrolyse all or a part of the alkoxy groups on the molecule. Sometimes, in order to effect the hydrolysis, a small amount of acid is required together with the water. Whenever "hydrolysate" or "partial hydrolysate" is used herein, it shall mean that it contains the hydrolysed silane or silanes, water for hydrolysis and the alcohol solvent formed by the cleavage of the alkoxy groups from the silane.

The treatment of the substrate can be carried out with the organofunctional silane or its partial hydrolysate alone but, contemplated within the scope of this invention, is a mixture of the organofunctional silane or its partial hydrolysate with an organosilane having the general formula $(\text{RO})_b\text{SiR}''_{4-b}$ wherein R has the same meaning as R above, R" can be a phenyl radical, or an alkyl radical of 1—4 carbon atoms and *b* has a value of 2 or 3. As indicated above for the formula:



the partial hydrolysates of $(\text{RO})_b\text{SiR}''_{4-b}$ are also part of this invention, R being preferably methyl.

The organofunctional silanes and the organosilanes are well-known commercial silanes and it is believed that their manufacture is adequately set out in the art and need not be repeated herein.

Whenever it is required to use a mixture of the silanes this is done by a simple mixing technique. The neat silanes may be mixed and then cohydrolysed or they may be hydrolysed separately and the hydrolysates mixed thereafter.

For the purpose of this invention, whenever a mixture of silanes is required, it is generally preferred that they be mixed in a ratio of 1:10 to 10:1 of organofunctional silane to organosilane on a weight basis. The ratio applies to the weight of the silanes before hydrolysis.

As indicated above, some of the silanes require the presence of a small amount of acid to enhance hydrolysis. Such acids are, for example, hydrochloric and acetic. This acid requirement is well-known in the silane hydrolysis art.

It is generally preferred that the silanes be hydrolysed prior to mixing. After the silanes have been hydrolysed, simple hand shaking of the hydrolysis vessel i.e. a bottle or flask will suffice to force the hydrolysis reaction. Generally, the hydrolysis mixture is used at this point without further modification or purification.

The amount of total silane in the hydrolysis mixture may be from 0.01 to 35 weight percent.

Whenever the silanes are to be used neat, they can be dissolved in solvents which are soluble with or miscible with water such as isopropanol, methanol, butanol, methylcellosolve or the like. Mixtures of such types of solvents are contemplated within the scope of this invention. These solvents may also be used with the hydrolysed silanes to enhance film forming abilities, for example.

The silanes or silane solutions may be applied to the substrate by any method which is convenient for the user. Such methods as dipping, flowing and spraying are most satisfactory for this invention.

The substrates useful in this invention are those which are solid substrates. Thus almost every useful solid substance which makes up an article can be the substrate of this invention. Such substrates may be, for example, plastics such as acrylonitrile-butadiene-styrene copolymers, sioplas (trade mark), crosslinked polyethylene (Dow Corning Corporation, Midland, Michigan), polycarbonates, polyethylene terephthalates such as Mylar (trade mark), (E. I. DuPont, Wilmington, Delaware), polyimides such as Kapton (trade mark), (E. I. DuPont), polyphenylene oxides such as Noryl (trade mark), (General Electric Co., Pittsfield, Massachusetts), polyphenylene sulfides such as Ryton (trade mark) (Phillips Chemical Co., Chicago, Illinois) and mineral filled nylons such as Minlon (trade mark) (E. I. DuPont), acrylics, urethanes epoxys and polyesters, just to name a few. Wood, cardboard, glass, metals, silicone rubbers and resins, urethane foams and polyvinylchloride foams are examples of other useful substrates.

One method taught herein consists in treating a solid substrate with an organofunctional silane, or a mixture of an organofunctional silane and an organosilane, and then allowing the silane treated surface to dry until the majority of the volatile materials have been removed from the treated surface. What is meant by volatile materials are the solvents, water and low molecular weight products that have been formed upon hydrolysis. What is meant by the "majority" of volatile materials is that the surface should be tack free or nearly tack free to the finger touch. This can be accomplished in a number of ways. For example, the treated surfaces can be left at room temperature for a period of time, perhaps days, to allow slow evaporation of the volatile materials into the atmosphere. Since time is usually a factor in commercial manufacture, however, the articles can be heated to remove volatiles. Vacuum can be applied to reduce the pressure and enhance volatilisation. We have used a number of methods to cause the removal of volatiles in a short period of time, such as 1—5 seconds, by heating and applying vacuum simultaneously.

Any method of volatile material removal that fits the manufacturers mode of manufacture is contemplated herein.

After the volatile materials have been removed, the thin metal coating is applied. Generally, any method by which thin, continuous metal coatings can be applied will suffice for this invention. Methods such as vapor deposition, electroplating, sputtering, ion plating and spraying are preferred. However, applying the thin, continuous metal coating can be accomplished from current methods of chemical solution application without detrimental effects on the adhesion promoting coating.

Metals that are useful in this invention are any metals that can be vapor deposited, electroplated, sputtered, ion plated, sprayed or applied from chemical solution. Such metals as copper, nickel, tin, silver, silver solder, gold, aluminum, platinum, titanium, zinc and chrome are preferred.

For the purpose of this invention, "thin" means the thickness of the metal film that is required to give a continuous, coherent film or coating. Generally, these coatings are less than 30 microns thick.

The articles prepared in this invention can be covered by clear protective coatings such as the silicone resins set forth in U.S. Patent 3,986,997. These materials are generally referred to as "topcoats" and are well-known in the art.

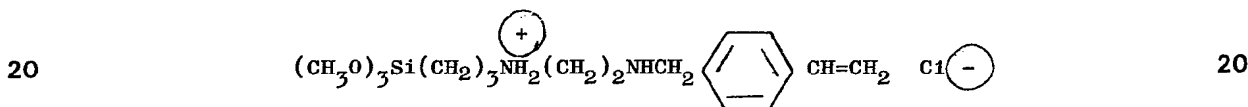
As indicated earlier, the surfaces of some substrates are sufficiently soft for them to be blemished by gouges or scratches during the manufacture of the article and in order to end up with a product that is aesthetically pleasing, the blemishes must be eliminated since simple metal plating over them with thin coatings or films allows the blemishes to show through.

Several silanes were evaluated in this invention by observing the adhesion of the metal coating. An appearance determination was made which was subjective and was based upon such characteristics as continuum of film, brilliance, specularly and the presence or absence of voids, pockmarks and the like. An excellent film is one which is continuous, without voids and/or pockmarks and has brilliance and high specularly. Specularity is a term used in the mirrored surfaces art which means the degree of light transmitted from the surface of a mirror, i.e. how good are the mirror properties. Adhesion was measured subjectively by rubbing the metal surface with a cloth saturated with acetone, methanol or isopropanol using moderate pressure unless a different method is indicated. The degree to which the metal surface survived this treatment is reported. No removal of the coating is considered "Excellent". "Good" is when some slight abrasion occurred. "Fair" means noticeable removal of metal. "Poor" means the removal of essentially all of the metallic coating. "None" means all the coating was removed.

Example 1

The following samples were prepared to observe which silanes or combinations of silanes would give the best enhanced adhesion between a given substrate and certain metals. Silanes or combinations of silanes were made at the concentrations shown by a method which involved the hydrolysis of each silane and the eventual combinations of the silanes to give the adhesion promoter used on the substrate. Table I in this example shows the various silanes tested.

Silane A is $(\text{CH}_3\text{O})_3\text{Si}(\text{CH}_2)_3\text{NH}(\text{CH}_2)_2\text{NH}_2$. Silane B is $(\text{CH}_3\text{O})_3\text{Si}(\text{CH}_2)_3\text{SH}$. Silane C is



Silane D is $(\text{CH}_3\text{O})_3\text{Si}(\text{CH}_2)_3\text{Cl}$, Silane E is $\text{phenylSi}(\text{OCH}_3)_3$, Silane F is $\text{propylSi}(\text{OCH}_3)_3$, Silane G is $\text{CH}_2=\text{CHSi}(\text{OCH}_3)_3$ and Silane H is $\text{HO}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3$.

Results are on Table II. IPA is isopropanol. MeOH is methanol. gms is grams.

Primer Preparation—Silane A (8 gms), IPA (8 gms) and 1.12 gms of water were mixed with agitation in a small 1 ounce glass bottle with a screw-top lid. The bottle was allowed to stand overnight (about 16—20 hrs). The material was then diluted with 800 gms of IPA upon transferring to a larger bottle.

Silane B (12.35 gms), IPA (717.65 gms), Glacial acetic acid (30 gms) and 40 gms of water were mixed together in the order given herein.

Silane C (24 gms) and 1.2 gms of water were mixed together and allowed to stand overnight (16—20 hrs). The material was then diluted by 800 gms of MeOH.

Silanes D, E, F and G were all handled in the same way. Three gms of the silane were treated with 27 gms of MeOH and then a small amount of acetic acid and enough water for complete hydrolysis was added, the mixture was shaken until clear and then was used without extensive aging.

H was used at 20 weight % in MeOH by using the same method as for D, E, F and G.

All primers were filtered before use.

All samples were hand dipped in the primer solutions and the excess material was allowed to drip off. The samples were then dried as shown in the tables.

Table I shows the silanes or combination of silanes that were used in the examples. "Sample #" is the reference number for the runs that were carried out for these examples. "Silane #1" is the organofunctional silane used in the sample. "Silane #2" is the organosilane used in the sample. "Acid added" and "H₂O added" means that the material was used as a hydrolysate, in the hydrolysis water, with the alcohol by-produced upon hydrolysis. In those cases where the silane was used neat, that is without prior hydrolysis, it is so indicated.

In Table II, the sample # from Table I indicates the silane(s) used in that particular run. If more than one run was made using the same silane but a different substrate or deposited metal, the run was designated a, b, c, etc. For example, from Table I, sample 4 is a primer made up of silanes C and B. Table II, sample 4a shows that the silanes were used in a ratio of 2.4:1, there was present 1.3 weight percent total silane in the primer, the substrate in the run was glass and the deposited metal was silver solder. Sample 4b of Table II shows the primer of sample 4 of Table I, having the same ratio of silanes at the same weight percent solids but the substrate is now acrylic sheet and the deposited metal is aluminum.

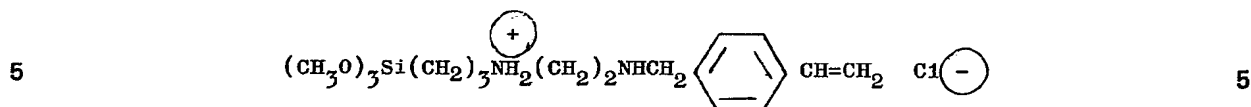
All samples in Table II were vapor deposited using a Mikros Vacuum Evaporator Model VE-10 manufactured by Thermionics Laboratories, Hayward, CA.

Example 2

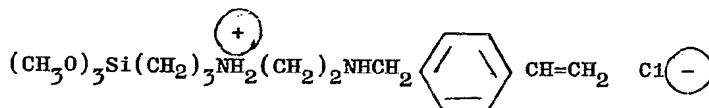
In order to compare the material of U.K. Patent 1,550,532 against the present invention, the following material was prepared. One hundred and eighty gms of a silicate-based polymer containing methyltrimethoxysilane were mixed with 20 gms of Acryloid OL-42 (Rohm & Haas Co., Philadelphia, PA). Acryloid OL-42 is an acrylic polymer similar to that found in the U.K. patent in Example 1. The

Acryloid is 80% solids in cellosolve acetate. One gram of hexamethylenetetramine catalyst was also added with agitation.

A primer (P) was prepared for use herein which consisted of 8 gms of $\text{HS}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3$ diluted with 800 gms of IPA, and 24 gms of 40% in MeOH of



diluted with 800 gms of additional MeOH. Seventy-five gms of the dilute $\text{HS}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3$ were mixed with 25 gms of the dilute



and a small amount of acetic acid and water and the mixture was stirred until clear.

10 A Lexan (trade mark) (General Electric Co., Schenectady, NY) polycarbonate slide was abraded with emery paper to simulate an abused article from manufacturing. After the slide was cleaned, it was measured off in 4 equal sections and marked and one section was dipped in the solution of primer (P) from above and then allowed to air dry for 20 minutes at room temperature. 10

15 The solution of acrylate polymer, silicate and alkoxy silane analogous to that found in Example 1 of U.K. patent 1,550,532 was then applied to 3/4 of the slide and the 1/4 primed area was overcoated thereby and air dried. The coating was then cured 15 min. at 70°C and 20 min. at 100°C. Next, 1/2 of the slide was dipped in a solution of P and allowed to air dry for 10 minutes at room temperature. Finally, the whole slide was vapor deposited with silver metal and cured for 15 min. at 100°C. If one were to lay the slide on its edge and to note the coatings or layers on the top of the slide, the left-most 20 1/4 section (denoted A) would have a silver coating only. Moving to the right, the next 1/4 section (denoted B) would have a top layer of silver covering a layer of the "1,550,532" polymer which in turn covers the polycarbonate slide. The third 1/4 section (denoted C) would have a top layer of silver covering a layer of P primer which in turn covers the 1,550,532 polymer which in turn covers the polycarbonate slide. The last 1/4 section (denoted D) consists of a top layer of silver, a second layer of the primer P, a third layer of the 1,550,532 polymer and finally a fourth layer of primer P. 25

Sections B, C, and D were scored into crosshatched squares by a sharp instrument to give 25 equal squares. Scotch Brand adhesive tape #650 (3M Co., St. Paul, Minnesota) was then pressed onto the crosshatched squares and removed forcibly. Recognizing that the most optimum conditions were not observed, the test was deemed to have been passed if at least 50% or more of the silver metal 30 remained intact. Table III shows the results. 30

Example 3

A silicone resin was prepared according to Example 2 of U.S. Patent 4,173,553 with the exception that the $\text{HS}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3$ was present at 10 weight percent $\text{CH}_3\text{Si}(\text{OCH}_3)_3$ at 40 weight percent and colloidal silica at 50 weight percent based on the weight of all three components. This 35 material is shown herein as "A". Another sample of silicone resin was prepared as shown in Example 1 of U.S. Patent 3,986,997, that is, the same material as above but without $\text{HS}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3$ and this was designated "B". The two materials were compared side-by-side for their ability to accept and adhere metals which were deposited thereon. Both materials were diluted to approximately 10% solids with isopropanol. 40

A clean square of Lexan (trade name) polycarbonate was dipped 1/2 into "A". The remaining 1/2 was dipped in "B". The sample was then air dried for 40 minutes at 25°C. The sample was then vapour deposited with silver. The sample then cured 1 hour at 125°C. The samples both had excellent specularly. The samples were subjected to a methanol rub to test the adhesion of the silver. The material "A" was clearly superior in retaining the silver metal. 40

Example 4

The silicone resin designated "B" in Example 3 above, was coated onto a clean Lexan (trade mark) polycarbonate square and cured 25 minutes at 100°C. One-half of the coated slide was then dipped into a primer designated earlier as primer P of Example 2 and this was allowed to dry for 2 minutes at 25°C. The square was then vapor deposited with silver and cured 1 hour at 125°C. The 1/2 50 side of the slide that had been primed with primer P of Example 2 showed superior retention of the silver deposited thereon. 50

The means of metal deposition described in this specification and claims are conventional means for depositing metals and it is believed that elaborate descriptions of such methods are not required by those skilled in the art.

Table I

Sample #	Silane #1	Silane #2	Solvent for #1	Solvent for #2	H ₂ O added	Acid added
1	A	—	IPA	—	yes	No
2	B	—	IPA	—	yes	yes
3	C	—	MeOH	—	yes	—
4	C	B	MeOH	IPA	yes	yes
5	B	E	IPA	MeOH	yes	yes
6	B	F	IPA	MeOH	yes	yes
7	B	G	IPA	MeOH	yes	yes
8	A	B	MeOH	IPA	yes	yes
9	—	E	—	MeOH	yes	yes
10	—	F	—	MeOH	yes	yes
11	—	G	—	MeOH	yes	yes
12	—	H	—	MeOH	yes	—

TABLE II

Sample #	Substrate	Deposited Metal Coating	Dry/Cure Conditions	Adhesion	* Ratio of Silanes #1:2	Total Weight % Silane(s)
1	glass	silver solder	30 min. @ 250°C/30 min. @ 150°C	Fair	—	1
2	glass	silver solder	30 min @ 25°C/30 min @ 150°C	Excellent	—	1.5
3	glass	silver solder	30 min @ 25°C/30 min @ 150°C	Good	—	0.4
4a	glass	silver solder	35 min @ 25°C/30 min @ 150°C	Excellent	2.4:1	1.3
4b	acrylic sheet	Aluminum	None/None	Fair	2.4:1	1.3
4c	ABS™	Aluminum	30 min @ 25°C/1 hr. @ 80°C	Good	2.4:1	1.3
	(Borg-Warner Chemicals, Parkersbury, W. Va)					
4d	Ryton-R8	Aluminum	30 min @ 25°C/1 hr. @ 80°C	Good	2.4:1	1.3
4e	Noryl	Aluminum	30 min @ 25°C/1 hr. @ 80°C	Good	2.4:1	1.3
4f	Minlon	Aluminum	30 min @ 25°C/1 hr. @ 80°C	Good	2.4:1	1.3
4g	Aluminum panel	chromium	30 min. @ 25°C/1 hr. @ 80°C	Excellent	0.8:1	1.35
4h	steel	silver	30 min. @ 25°C/65 min @ 100°C	Excellent	0.6:1	1.1
4i	Sioplas® crosslinked polyethylene	Aluminum	5 min. @ 25°C/60 min @ 75°C	Excellent	2.4:1	1.3
4j	polyethylene	Aluminum	5 min. @ 25°C/60 min. @ 75°C	Excellent	2.4:1	1.3
4k	Lexan® polycarbonate	silver	5 min. @ 25°C/10 min. @ 100°C	Excellent	0.6:1	1.1

*A=acetone

I=IPA

M=MeOH

**no acid, no water

***used alone—not within scope of this invention.

Table II (cont.).

Sample #	Substrate	Deposited Metal Coating	Dry/Cure Conditions	Adhesion	*	Ratio of Silanes #1:2	Total Weight % Silane(s)
4l	wood	silver	60 min. @ 25°C/38 min. @ 75°C	poor	A	0.6:1	1.1
4m	paper	silver	10 min. @ 25°C/38 min. @ 75°C	good	A	0.6:1	1.1
4n	silicone circuit board	silver	60 min. @ 25°C/38 min. @ 75°C	Excellent	A	0.6:1	1.1
4o	silicone epoxy circuit board	silver	60 min. @ 25°C/38 min. @ 75°C	Good	A	0.6:1	1.1
4p	Teflon® (E. I. DuPont) cloth	silver	2 min. @ 25°C/48 min. @ 100°C	None	/	0.6:1	1.1
4q	polyester	silver	30 min. @ 25°C/30 min. @ 100°C	Excellent	A	0.6:1	1.1
4r	glass	Aluminum	30 min. @ 25°C/60 min. @ 80°C	Good	A	0.8:1	1.3
4s	glass	copper	30 min. @ 25°C/30 min. @ 150°C	Excellent	A	0.8:1	1.35
4t	glass	chromium	30 min. @ 25°C/30 min. @ 150°C	Excellent	A	0.8:1	1.35
4u	glass	nickel	30 min. @ 25°C/30 min. @ 150°C	Excellent	A	0.8:1	1.35
4v	glass	tin	30 min. @ 25°C/60 min. @ 100°C	Excellent	A	0.6:1	1.1
4w	glass	silver	30 min. @ 25°C/60 min. @ 80°C	Excellent	A	2.4:1	1.3
4x	glass	gold	30 sec. @ 25°C/30 min. @ 100°C	Excellent	A	0.8:1	1.35
2a**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Good	A	—	10.0
2b**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Good	A	—	100
2c**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Fair	A	—	0.1
2d**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Fair	A	—	0.01
3a**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Good	A	—	100.0
3b**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Good	A	—	10.0
3c**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Poor	A	—	1.0
3d**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	None	A	—	.1
3e**	glass	silver	30 min. @ 25°C/10 min. @ 120°C	None	A	—	0.01
4y	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Fair	A	2.4:1	1.1
4z	glass	silver	30 min. @ 25°C/10 min. @ 120°C	Fair	A	0.6:1	1.1
5	glass	silver	1 min. @ 25°C/60 min. @ 100°C	Good	A	1:1	2.0
6	glass	silver	5 min. @ 25°C/30 min. @ 100°C	Excellent	I	1:1	20.0
7	glass	silver	5 min. @ 25°C/30 min. @ 100°C	Poor	I	1:1	20.0
8	glass	silver	2 min. @ 25°C/30 min. @ 100°C	Excellent	I	1:1	2.0
9***	glass	silver	30 min. @ 25°C/30 min. @ 100°C	None	A	—	10.0
10***	glass	silver	30 min. @ 25°C/30 min. @ 100°C	None	A	—	10.0
11***	glass	silver	30 min. @ 25°C/30 min. @ 100°C	None	A	—	10.0
12	glass	aluminum	5 min. @ 25°C/30 min. @ 100°C	Good	A	—	2.0

*A=acetone

I=IPA

M=MeOH

**no acid, no water

***used alone—not within scope of this invention.

TABLE III

	Sample	Pass/Fail	% Retention of Silver	Appearance of Remaining Silver	
5	B	failed*	0	—	5
	C	passed	65	smooth/brilliant	
	D	passed	65	smooth/brilliant	

*loss of adhesion occurred at the silver/basecoat interface.

Claims

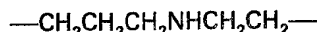
- 10 1. A method of forming an adherent metal surface on a substrate comprising the steps of: 10
 (i) treating a solid substrate with at least one organofunctionalsilane, or a partial hydrolysates thereof, having the general formula (I):



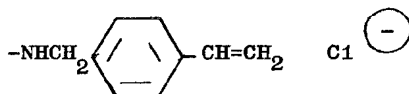
- 15 or a mixture of such an organofunctional silane or the partial hydrolysate(s) thereof with a second silane, or a partial hydrolysates thereof, which has general formula (II): 15



in which formulae R is an alkyl radical of 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a



- 20 radical,
 X is an —NH₂,



- SH, OH or Cl radical, R'' is a phenyl radical, or an alkyl radical of 1—4 carbon atoms, and
 a and b each have a value of 2 or 3, c has a value of 0 or 1 and a+c=3;
 25 (ii) drying the silane treated surface until the majority of volatile materials have been removed; 25
 and, thereafter,
 (iii) depositing a metal on the silane treated surface to form a thin continuous film or coating thereon.

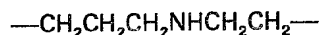
2. A method of forming an adherent metal surface on a substrate comprising the steps of:
 30 (i) treating a solid substrate with a curable organic or silicone basecoat and curing said basecoat; 30
 (ii) treating said cured basecoat with at least one organofunctional silane, or a partial hydrolysate(s) thereof, having the general formula (I):



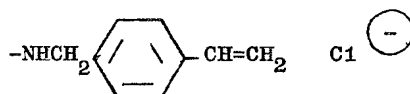
- or a mixture of such an organofunctional silane, or the partial hydrolysate(s) thereof, with a second silane, or a partial hydrolysate(s) thereof, which has the general formula (II): 35



in which formulae R is an alkyl radical of 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a



- 40 radical,
 X is an —NH₂,



—SH, OH or Cl radical, R" is a phenyl radical, or an alkyl radical of 1—4 carbon atoms, and *a* and *b* each have a value of 2 or 3, *c* has a value of 0 or 1 and *a*+*c*=3;

(iii) drying the silane treated surface until the majority of volatile materials have been removed and, thereafter,

5 (iv) depositing a metal on the silane treated surface to form a thin continuous film or coating thereon. 5

3. A method of forming an adherent metal surface on a substrate comprising the steps of:

(i) treating a solid substrate with a curable organic or silicone basecoat which contains at least one organofunctional silane, or a partial hydrolysate(s) thereof, having the general formula

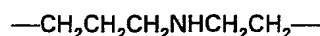
10 (I): 10



or a mixture of such an organofunctional silane, or the partial hydrolysate(s) thereof, with a second silane, or a partial hydrolysate(s) thereof, which has the general formula (II):

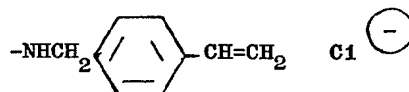


15 in which formulae R is an alkyl radical or 1—4 carbon atoms, R' is a difunctional hydrocarbon radical having from 1—12 carbon atoms or a 15



radical,
X is an —NH₂,

20



20

—SH, OH or Cl radical, R" is a phenyl radical, or an alkyl radical of 1—4 carbon atoms and *a* and *b* each have a value of 2 or 3, *c* has a value of 0 or 1 and *a*+*c*=3;

(ii) drying the basecoat until the majority of volatiles have been removed; and, thereafter;

(iii) depositing a metal on the basecoat to form a thin continuous film or coating thereon.

25 4. A method as claimed in claim 1, 2 or 3 wherein the metal deposited is selected from a group consisting of copper, nickel, tin, silver, silver solder, gold, aluminum, platinum, titanium, zinc and chrome. 25

5. A method as claimed in claim 1, 2 or 3 wherein the substrate is selected from a group consisting of plastics, wood, cardboard, glass, metals, silicone rubbers and silicone resins.

30 6. A method as claimed in claim 1, 2 or 3 wherein the substrate is in the form of a lens. 30

7. The method of claim 1, 2 or 3 wherein there is also present a clear topcoat on the deposited metal surface.

8. A method as claimed in any one of claims 1 to 3, substantially as herein described with reference to any one of the specific examples.

35 9. An article prepared by the method of any one of claims 1 to 8. 35